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XXXIV. *Difficulties in the* Newtonian *Theory of Light, conſidered and removed, by the Rev.* S. Horſley, *LL. B. F. R. S.*

Read Dec. 20, 1770.

DR. Franklin, in a letter to a correſpondent at New-York, the 23d of that valuable collection with which the public was obliged in the latter end of the year 1768, propoſes ſome *objections to the Newtonian theory of light.* His words are theſe. "I am much in the dark about "light. I am not ſatisfied with the doctrine that "ſuppoſes particles of matter called light, continual-"ly driven off from the ſun's ſurface with a ſwiftneſs "ſo prodigious. Muſt not the ſmalleſt particle con-"ceivable have, with ſuch a motion, a force exceed-"ing that of a twenty-four pounder diſcharged from "a cannon? Muſt not the ſun diminiſh exceedingly "by ſuch a waſte of matter, and the planets recede "to greater diſtances by the leſſened attraction? Yet "theſe particles with this amazing motion will not "drive before them, or remove, the leaſt and lighteſt "duſt they meet with: and the ſun, for aught we "know, continues of his antient dimenſions, and his "attendants move in their antient orbits." Dr.

 Franklin's

Franklin's questions are of some importance, and deserve a strict discussion.

Upon the supposition that light is a copious emanation of innumerable small particles of matter from the sun, I had once occasion to enquire, what the force of motion produced in every such emission could possibly amount to at the utmost.

For this purpose, I made an estimate of the greatest probable magnitude of the particles of light; and of the greatest density of each.

I likewise computed the greatest number of such particles, that could possibly fly off at once from the surface of the sun; supposing the sun's horizontal parallax to be no more than 8″.

These computations, with an account of the principles on which they were founded, having been already given to the public[a]; I shall make use of the results (which I shall here briefly state) as data for the discussion of Dr. Franklin's questions.

I suppose the particles of light to be equal spherules. This, perhaps, is not the case. Each color has probably its own size; but, there will be a mean size, which is sufficient for my purpose.

This mean size I suppose to be so small, that the diameter of each spherule does not exceed one millionth of one millionth of an inch. I shall shew hereafter, that there is much reason to suppose that the particles of light are in fact much less than spherules of this diameter.

[a] In a little treatise, entitled, The Power of God, deduced from the computable instantaneous Productions of it in the Solar System.

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I ſuppoſe the denſity of each particle three times that of iron[b]. The number of ſuch ſpherules that contain as much matter as an iron ball of one yard diameter, I have found to be 15552 XXXVI[c d]; conquently 576 XXXVI ſuch ſpherules contain as much matter as an iron ball of 1 foot diameter.

Let ſuch a ball be ſuppoſed to move uniformly with a velocity that ſhould carry it 1000 yards in $1''$.

The light of the ſun traverſes the ſemidiameter of the orbis magnus in $7'$ nearly.

In the enſuing calculations, I ſhall reckon the ſun's horizontal parallax $9''$.

According to this hypotheſis, the ſemidiameter of the orbis magnus will contain 22919 ſemidiameters of the earth.

In $1''$ of time, light, according to the velocity aſſigned to it, traverſes $\frac{1}{420}$th of this ſpace, or 54,57 ſemidiameters of the earth, or 381092323 London yards.

Hence the velocity of each particle of light, will be to that of the iron ball moving 1000 yards in $1''$ as 381092 to 1, very nearly.

And the ball being 1 foot diameter, it has been ſhewn that the matter in each particle is to the matter in the ball, as 1 to 576 XXXVI.

Hence the force of the motion in each particle of light, is to the force of motion in the ball as 381092 to 576 XXXVI; that is, as 1 to 1511444 XXVII, or,

[b] Inſtantaneous Product. &c. p. 30.

[c] Ibid.

[d] The Roman numerals placed after the Arabic characters, denote the number of zeros that muſt be added to the Arabic figures, to compleat the expreſſion of the number intended.

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it is equal to the force of motion in an iron ball of 1 foot diameter moving $\frac{1}{1511444\ \text{xxvii}}$th of 1000 yards in 1″, or to that of an iron ball of 1 inch diameter moving $\frac{1}{874679\ \text{xxi}}$th of 1 yard in 1″, or to that of an iron ball of ¼ of an inch diameter moving $\frac{1}{13666\ \text{xxi}}$th of 1 yard in 1″; that is, moving less than $\frac{1}{4555\ \text{xxi}}$ of 1 foot in 1″; that is, moving less than a foot in 4555 xx.1 seconds, or in more than *one hundred forty four thousand millions of millions of Egyptian years*: or the force of motion in each particle of light coming from the sun, is less than that in an iron ball of ¼ of an inch diameter, moving at the rate of less than an inch in 12 thousand millions of millions of Egyptian years.

Dr. Franklin's first question is answered. A particle of matter, which is probably larger than any particle of light, moving with the velocity of light, has a force of motion, which, instead of exceeding the force of a twenty-four pounder discharged from a cannon, is infinitely less than that of the smallest shot discharged from a pocket pistol, or less than any that art can create.

I proceed to the other questions—And, I think that I shall make it appear, that it is very possible that light may be produced by a continual emission of matter from the sun, without any such waste of his substance as should sensibly contract his dimensions, or sensibly alter the motions of the planets, within any moderate length of time.

Indeed, I do not think it necessary to the production of any of the phænomena of light, that the emanation

emanation from the ſun ſhould be *continual* in a ſtrict mathematical ſenſe, or without any interval. It ſeems ſufficient to all purpoſes, that the intervals ſhould be exceeding ſhort. But this I only mention.—I think it poſſible that a *continual* emanation might ſubſiſt, without any ſuch dangerous conſequences to the ſolar ſyſtem, as Dr. Franklin apprehends. Dr. Franklin's character is not more diſtinguiſhed by his ſuperior talents, than by a candor truly philoſophical. And upon this circumſtance, I build the ſtrongeſt confidence, that he will not be offended, that I differ from him: that, as a friend to enquiry, he will be pleaſed that I take the liberty to communicate my own notions, however oppoſite they may be to his.

It will be eaſily underſtood, that a continual emanation from the ſun does not neceſſarily imply a continual waſte, or loſs, equal to the emanation.—If light is continually iſſuing from the ſun in all directions, part of this is continually returning to him, by reflection from the planets, and other light is continually coming to him, from the ſuns of other ſyſtems. It is true, that the light which he receives, is but a very ſmall part of the light which he gives. For if the light always *coming* to the ſun were equal to the light always *going from* him, our atmoſphere would be as ſtrongly enlightened in the night as in the day.—But this is not the caſe; and the proportion of the light that *comes*, to the light that *goes*, cannot be greater than that of night-light at a medium, to day-light at a medium—ſtill it is ſomething—and the continual loſs of ſubſtance that the ſun ſuſtains cannot be more than the difference between the light that he gives, and the light that he receives.

And therefore, if there were no other recruit of the ſun's ſubſtance (which is by no means a probable ſuppoſition) yet the continual waſte will, on this account alone, be leſs than the continual emiſſion; and the ſun cannot loſe ſo much of his ſubſtance as a ſingle emiſſion of light contains, but in ſome determinate time. I ſhall ſuppoſe that the ſun gives ſo much more than he receives, that he loſes the amount of one emiſſion in every ſecond of an hour. Let us ſee what will be the conſequence. Every particle of light that iſſues from the ſun, muſt leave a ſpherical vacuity of one millionth of one millionth of an inch diameter.

The greateſt number of particles of this ſize that can iſſue from the ſurface of the ſun at once, if the horizontal parallax be 9″, is 104666 XLI [e], becauſe this is the greateſt number of ſuch particles that would have room to lie at once upon his ſurface. And the ſame will be the greateſt number of ſpherical vacuities made by one emiſſion.

Many of theſe vacuities are no ſooner made, than they are filled up by the light that is coming to the ſun from other ſyſtems, or returning to him from the bodies of his own, or, perhaps with other matter which he may receive in various emanations from the planets; for I ſtrongly ſuſpect that a perpetual circulation of finer matter may ſubſiſt between all the large bodies of the univerſe. The emiſſion of light, however, is ſuppoſed ſo far to exceed the whole

[e] The greateſt number of particles that can iſſue from the ſun at once, was reckoned in the Inſtant. Product. 132467 XLI; but then the ☉'s parallax was reckoned only 8″.

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ſupply, that in every ſecond, over and above the vacuities that have been filled up with adventitious matter, the foregoing number, 104666 XLI, have been formed that have received no ſuch ſupply. The *fluid* matter of the ſun [f] ruſhes from all ſides into theſe, and fills them up to its own level. The ſun by this means ſhrinks a little, and loſes, once in every ſecond, ſo much of its ſolid content, as the ſolid contents of theſe vacuities amount to.

I have found that the ſolid contents of 46656 XXXVI ſuch vacuities are equal to the ſphere of one yard [g].

Therefore the ſolid contents of 104666 XLI ſuch vacuities, are equal to 224335½ times the ſphere of one yard. And ſo much is the ſun's ſolid content diminiſhed every ſecond.

The ſphere of the earth is to the ſphere of one yard, as 27247031 XIV to 1 [h].

Therefore the ſphere of the earth is to 224335½ times the ſphere of one yard as 121456 XI to 1.

Therefore the ſun loſes *an earth* of its ſolid content in 121456 XI ſeconds, or 385130000 Egyptian years nearly.

If the ſun's parallax be 9″, the ſolid content of the earth is $\frac{1}{1217420}$ of the ſolid content of the ſun.

Therefore, in 385130000 Egyptian years, the ſun ſhould loſe $\frac{1}{1217420}$th of his ſolid content, and conſequently in the ſame time the diameter of the ſun

[f] I ſuppoſe the ſun to be a fluid maſs: by this hypotheſis, I give the utmoſt force to Dr. Franklin's objection; for, the more perfectly the ſun is fluid, the more ſuddenly will the vacuities be filled up.

[g] Vide Inſtant. Product. p. 30.

[h] Ibid. p. 16.

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ſhould loſe $\frac{1}{3852260}$ th of its whole dimenſions. And in the ſame time the apparent diameter ſhould loſe the like part of its quantity, if the diſtance between the earth and ſun remained unaltered.

The ſun's mean apparent diameter contains 1922 ſeconds. Therefore $\frac{1}{3852260}$ th of the ☉'s apparent diameter, is $\frac{1}{1900}$th of one ſecond very nearly. So inconſiderable would be the whole diminution of the ſun's apparent diameter, that could ariſe from the waſte of his ſubſtance, in 385130000 Egyptian years.

But the waſte of the ſun's ſubſtance muſt leſſen the attraction between the earth and ſun. As the attraction leſſens, the earth will recede to greater diſtances. And hence there will ariſe a further diminution of the ſun's apparent diameter, and a prolongation of the anomaliſtic year.

The denſity of each particle of light has been ſuppoſed three times that of iron, or 23 times the mean denſity of the earth [i]. Therefore, as often as the ſun's loſs by light amounts to an earth in ſize, it will amount to 23 earths in matter.

The matter of 23 earths is $\frac{1}{13232}$d of the ſun's matter, if the ſun's parallax be $9''$.

Therefore in 385130000 Egyptian years the ſun loſes $\frac{1}{13232}$d of his matter; and the gravitation towards the ſun, at any given diſtance, diminiſhes in

[i] I reckon the mean denſity of the earth no greater than that of common water. It is certain that it cannot be leſs. Sir Iſaac Newton reckons it 5 or 6 times greater; but I confeſs that I am not ſatisfied with his reaſons for making it ſo great. If I have under-rated it, I have, in ſo doing, given the advantage to Dr. Franklin's objection.

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the ſame proportion. But this alteration is much too ſmall to diſcover itſelf in the motions of the earth or any of the planets. I will not at preſent conſider, by what law the diſtance of the planets from the ſun would increaſe, becauſe the enquiry could not be reduced to a ſmall compaſs; but it is obvious, that, whatever that law may be, it muſt ariſe ſolely from the diminution of gravitation: and the like is to be ſaid of the increaſe of the anomaliſtic periods. And therefore, while the diminution of gravitation is inſenſible, the changes in theſe circumſtances muſt be inſenſible too. Of all the changes to which our ſyſtem may be obnoxious, thoſe which ſhould ariſe from the waſte of the ſun's ſubſtance in light, upon the ſuppoſition that light is an actual emanation of matter from the ſun, reckoning that waſte at the utmoſt, are perhaps the leaſt conſiderable.

In the foregoing computations, the inſtantaneous emiſſion of light has been greatly over-rated. For if the particles of light were of the magnitude and denſity which has been aſſigned to each, and were to iſſue from the ſun in the cloſe arrangement that has been ſuppoſed, they would form a ſort of cruſt upon the ſun's ſurface, at leaſt 12 times more denſe than water, *i. e.* 9600 times more denſe than our atmoſphere in the parts next the earth's ſurface, if the denſity of common water compared to that of air be reckoned only as 800 to 1 [k]. But if the denſity of light upon the ſun's ſurface be 9600 that of our air, its denſity when it arrives at the earth, or its

[k] It is well known that the denſity of water to that of air, is as 850 to 1 at leaſt.

denſity upon the ſurface of the orbis magnus[t], ſhould be more than $\frac{1}{5}$th part of the denſity of our air. When ſubſtances of different ſpecific gravities, as a piece of gold and a piece of cork, deſcend, in the exhauſted receiver, with equal velocities, and fall equal heights in the ſame time, it is obvious, that the denſity of the medium, through which they fall, bears no ſenſible proportion to the denſity even of the lighter ſubſtance. The medium through which ſuch ſubſtances fall, in a tranſparent glaſs receiver, is compoſed of ſome ſmall portion of rarified air, and, to all appearance, of the ſame quantity of light, as the receiver contains before exhauſtion. For the quantity of light, in a tranſparent receiver, can by no means ſuffer any diminution, by the action of the air-pump. The denſity of the light therefore, in our air, is certainly too ſmall to bear any ſenſible proportion to that of gold or even of cork. And the denſity of cork bears, though a great, yet a finite and a ſenſible proportion to that of the atmoſphere; becauſe in air gold and cork do not deſcend with equal velocities. Hence, I think, I may conclude with the greateſt certainty, that the denſity of the ſun's light at the earth, or upon the ſurface of the orbis magnus, is too ſmall to bear any ſenſible proportion to the denſity of common air; and I ſhall hardly underrate the denſity of the light, if I reckon it only $\frac{1}{10000}$th part of the denſity of the air, or $\frac{1}{8000000}$th part of the denſity of common water. Suppoſe this

[t] By the ſurface of the orbis magnus, I mean to denote a particular place in abſolute ſpace, namely the ſurface of that ſphere which is concentric with the ☉, and hath the earth's mean diſtance from the ☉ for its ſemidiameter.

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to be the denſity of light upon the ſurface of the orbis magnus, and it will be found by computation, that its denſity upon the ſun's ſurface, muſt be leſs than $\frac{1}{173}$d of the denſity of common water.

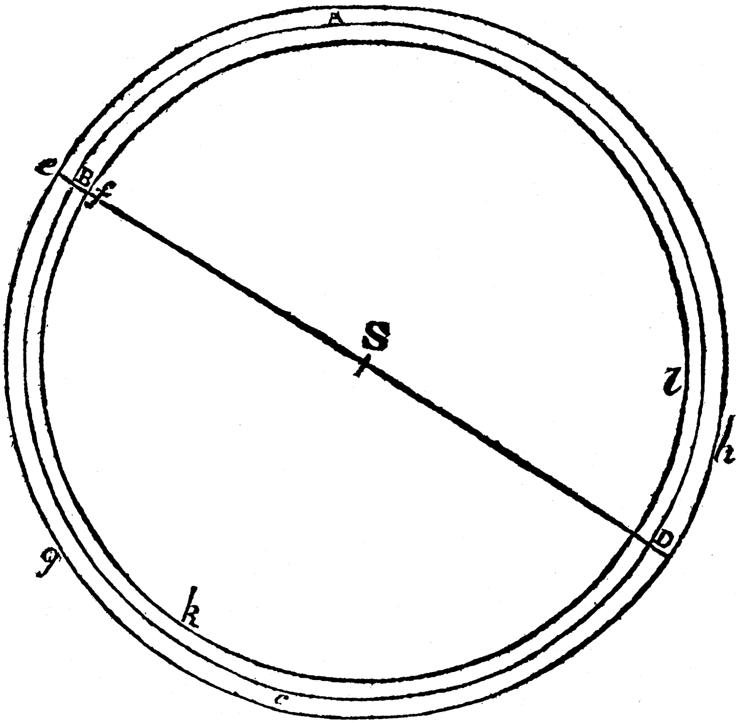
From theſe conſiderations, I think it may be concluded with the greateſt certainty, that the quantity of matter that iſſues from the ſun in light, has been greatly over-rated in the foregoing computations.

I apprehend, however, that the denſity of each ſeparate particle cannot be leſs than has been ſuppoſed: but that the magnitude of each is leſs, and the arrangement leſs compact[m]. Let the denſity of each, and the number that iſſues at any one time from the ſun, remain as before; and let us conſider, in what proportion the magnitude of each particle, muſt be diminiſhed, ſo that they may altogether form a fluid, on the ſun's ſurface, 173 times leſs denſe than water. Let ABCD repreſent a ſection of the ſun's ſphere, through the centre S[n]. In the ſpherical ſurface ABCD, take any point B. Join SB, and take B*e*, B*f*, each equal to the ſemidiameter of a particle of light. Upon the centre S, at the diſtances S*e*, S*f*, imagine two other ſpheres, *e g h*, *f k l*, one incloſing, the other incloſed within the ſphere ABCD. The ſolid ſpace *e f k l g h*, is the ſpace that contains all the particles of light (with their interſtices) that iſſue together from the ſpherical ſurface ABCD; and becauſe *e f* bears an exceeding ſmall proportion to S B, therefore the ſpherical ſurfaces *e g h*, *f k l*, are very nearly equal each to the other, and to the ſphe-

[m] Vide Inſtant. Product. p. 37. [n] See the fig. p. 429.

rical ſurface ABCD; and the ſolid ſpace contained between them is very nearly equal to a cylinder, upon a baſe equal to the ſpherical ſurface ABCD, and of altitude equal to ef. Therefore diminiſh the diameter of each particle of light, that is, diminiſh ef, in any proportion whatſoever, and the ſolid ſpace ABCD $\times ef$ diminiſhes in the ſame proportion. And if the matter in that ſpace were given, the denſity of it would always be as $\frac{1}{ef}$. But the matter of each particle of light, and conſequently the matter of the given number in the ſpace ABCD $\times ef$, is always as ef^3. Therefore the denſity of the ſubſtance formed by light in the ſpace ABCD $\times ef$, is always as $\frac{ef^3}{ef}$, or as ef^2.

That is, the number of ſpherical particles of light, in the ſolid ſpace ABCD $\times ef$, being given, and the denſity of each particle, and the ſpherical ſurface ABCD being given, the ſquare of the diameter of each particle will be as the denſity of the ſubſtance they compoſe, upon the ſurface of the ſun. But it has been found, that if the diameter of each ſpherule were one millionth of one millionth of an inch, the greateſt number of ſuch ſpherules, that the ſun's ſurface can contain at once, would, with the denſity which has been aſſigned to each ſeparate particle, form a ſubſtance upon it 12 times more denſe than water. Therefore, that the ſame number of ſuch particles ſhould form a ſubſtance about 173 times leſs denſe than water, the diameter of each muſt not exceed $\frac{10}{456}$th of one millionth of one millionth of an inch. But I have ſhewn that the greateſt



greateſt probable denſity of light upon the ſun's ſurface does not amount to 173d part of the denſity of common water. Therefore the diameter of each ſpherulé does not exceed $\frac{10}{456}$th, or more accurately, $\frac{1000}{45648}$th, of one millionth of one millionth of an inch; and is probably ſtill leſs [n]. More than 95100 ſpherules of this ſize go to make up one of the ſize firſt aſſumed. Therefore, though the ſun ſhould loſe as much

[n] Inſtant. Product. p. 38—41.

matter

matter, as can be ſuppoſed to be contained in any ſingle emiſſion of light, 95100 times in every ſecond, no ſenſible alterations in the ſyſtem could take place in millions of years. And perhaps light does not iſſue from the ſun ſo frequently as 95100 times in a ſecond.

June 13, 1770. S. Horſley.

P. S. The late Dr. Pemberton, of Greſham College, to whom the foregoing paper was communicated, about twelve months before his death, in a letter with which he favoured the authour, upon the ſubject, remarked, that he had no material objection to any part of the reaſoning, except it was, that the particles of light are too peremptorily ſpoken of as ſpherules. Their real figure is quite unknown; but the probability is, that they are not ſpherical, ſince Sir Iſaac Newton found that their different ſides have different properties. As the like objection may occur to others, it may not be improper to add a few words to obviate it. I would by no means be underſtood to aſſert, that the particles of light are of a ſpherical figure. But, whatever their *figure* may be, I conceive that their *ſize* muſt be ſo ſmall, that the diagonal of each little ſolid cannot exceed one millionth of one millionth of an inch, or, at leaſt,

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that each is capable of being circumſcribed within a ſphere of that diameter. To the reaſons which are given for making them ſo ſmall, in the treatiſe ſo often referred to, I ſhall here add another, which may perhaps be more generally convincing: namely, that theſe bodies muſt be ſo minute as to find room to enter in, in ſwarms, at the pupils of the eyes of the ſmalleſt microſcopic animals, and not to injure, by their ſtroke, the very delicate fibres of their optic nerves, nor to lacerate the edges of the uvea; which thoſe that enter near the ſides of the perforation, if their figure be not round, muſt often bruſh with their angles, as they paſs by. Now, if it be granted, that the greateſt diagonal of each ſolid corpuſcle of light does not exceed one millionth of one millionth of an inch, or that each is capable of being circumſcribed with a ſphere of that diameter; then, the ſolid content of a ſphere of that diameter is the *maximum* of the ſolid content of each corpuſcle, and the matter in ſuch a ſphere, of due denſity, is the maximum of the matter in each corpuſcle. The maximum therefore of the force of motion in each particle, is the force of a ſpherule of the ſize aſſumed, moving with the known velocity of light; and therefore, be the figure what it will, my concluſion (p.420.) which reſts entirely on the maximum of ſize and matter, will ſtill hold good, unleſs it can be ſhewn that I have under-rated the denſity of each particle; and even if it could be proved that I have aſſumed the denſity too ſmall, in the proportion of 1 to 12 thouſand times the ſquare of one million, ſtill the general concluſion will not be ſhaken: for this vaſt increaſe of the denſity will raiſe the force of motion, in each corpuſcle

pufcle, to no more than that of an iron ball $\frac{1}{4}$ of an inch diameter, moving one inch in a whole year.

Again, in the diagram, p. 429, S B being the diameter of the fun, and f B, B e being each the half of one millionth of one millionth of an inch, the fpace contained between the fpherical furfaces $f\,k\,l$, $e\,g\,h$, is the maximum of the fpace that the particles of light with their due proportion of interftice can fill, as they ftart forth from the furface of the fun. For, whatever their figure be, it muft be fuch a one as can be laid between thefe two fpherical furfaces. Now the quantity of matter in this fpace, muft not be greater, than it would be upon the hypothefis that each figure was fpherical, and the number of fpherical particles the greateft poffible. Since, upon that hypothefis, the denfity of matter, crowded into this fpace, is vaftly too great, to be confiftent with the appearances of nature (vide p. 425, 426.); and confequently a greater denfity would be more inconfiftent. Therefore the maximum of the matter, and confequently, if the denfity of each feparate particle has been rightly affumed, the maximum of the folid content, in each emiffion of light, is what I have made it; at leaft it does not exceed what I have made it, be the figure of the particles what it will; and my conclufions (p. 424 and 425.) which reft entirely upon the maximum of the folid content, and that of the matter, and are the ftronger the lefs thefe maxima be, will ftill hold good. But if thefe conclufions ftand, the objections moved by Dr. Franklin vanifh.

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The only part of my reaſoning which will be affected, by ſuppoſing the figure of the particles of light not to be ſpherical, will be that, (p. 427, &c.) in which I attempt to ſhew, in what proportion the magnitude of each particle, and the matter, contained in each emiſſion, muſt be leſs than the maximum, in order to make the denſity of light no greater, than may be conſiſtent with the appearances of nature. Here indeed the figure of the corpuſcles is of great importance. The diminution neceſſary will be very different in different figures, and the figure, I confeſs, may be ſuch, as to make it much leſs, than what I have ſhewn to be requiſite upon the ſpherical hypotheſis. However, if $\frac{1}{10000}$th part of the denſity of our air be admitted to be as great a denſity, as can reaſonably be allowed to light, at the ſurface of the orbis magnus, the matter of each emiſſion muſt not, upon any hypotheſis of the figure of the corpuſcles, exceed $\frac{1}{2084}$th of the maximum.

For, in order to bring the denſity down, from the maximum to any other given limit, either the matter muſt remain unaltered, and the ſpace, which it is ſuppoſed to occupy, be encreaſed, in the proportion in which the denſity is to be diminiſhed; or the ſpace muſt remain unaltered, and the matter be diminiſhed in proportion to the denſity; or, if both ſpace and matter be altered, the matter muſt be changed in the proportion compounded of the two, in which both ſpace and denſity are varied. Now the ſpace which we ſuppoſe the light to occupy, as it is emerging from the ſurface of the ſun, muſt not exceed the ſpace contained between the ſpherical ſurfaces *e g h*, *f k l* (fig. p. 429.). For that ſpace, as has been

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obſerved, is the maximum. This ſpace may be diminiſhed; but if it be diminiſhed, the matter being diminiſhed as the ſpace and as the denſity jointly, muſt be more diminiſhed than in the ſimple proportion of the denſity. Therefore the diminution of the matter will be the leaſt poſſible, if, the ſpace being ſuppoſed to continue at its maximum, the matter be diminiſhed in the ſimple proportion of the maximum of the denſity to the denſity required. Various formations of the particles of light might be thought of which would anſwer this purpoſe. It might be anſwered, indeed, upon the ſpherical hypotheſis, by diminiſhing the number of ſpherules, retaining the maximum of their ſize; or retaining the maximum both of ſize and number, if it can be thought reaſonable to diminiſh the denſity of each particle. But upon any hypotheſis, the diminution of matter cannot be leſs than has been ſaid. That is, the matter of each emiſſion cannot poſſibly exceed $\frac{1}{2084}$th of the maximum. For the proportion of the maximum of the denſity to the denſity required, will be found by computation, to be that of 2084 to 1, very nearly. Therefore the utmoſt probable amount of one emiſſion is $\frac{1}{2084}$th of the maximum, be the figure of the corpuſcles what it will. And the ſun may loſe the quantity of a whole emiſſion 2084 times in a ſecond without any ſenſible conſequences.

I cannot apprehend from, any quarter, ſo unphiloſophical an objection, as that the extreme minuteneſs of the particles of light, which I have ſhewn to be neceſſary, if light be really matter, is

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an argument againſt their exiſtence. Size is a meer accident, and no part of the eſſence of any being. Great and ſmall, applied to finite things, are purely terms of compariſon. One Being only is abſolutely Great: he whoſe ſubſtance pervades and fills the whole and every part of Abſolute Space; becauſe in reſpect of Him, all things that are, are little.

Notwithſtanding the maximum of moving force, in each particle of light is ſo inconſiderable as I have ſhewn it to be, yet the number of particles, out of each emiſſion, which are directed towards the earth, and fall upon its enlightened hemiſphere, being exceeding great, it may perhaps be imagined, that the, force impreſſed by them all upon the earth, if they all actually ſtrike its ſurface, may amount to ſomething worth attending to. I have taken the pains to ſatisfy myſelf upon this queſtion, and ſhall briefly mention the reſult of my computations.

Reckoning every emiſſion at its maximum, I find that the number of the particles, out of each, which ſhould fall upon the earth's enlightened hemiſphere, is 492023xxxi, or that of which the logarithm is 36.6919854. The moving forces of this whole number amount to as much, as the force of an iron ball, of one yard diameter, flying 68 mile and 887 yards in one ſecond. But the progreſſive force, which they might communicate to the earth, does not exceed that of an iron ball of the ſame ſize, flying 34 mile and 443 yards in one ſecond °. And, if this whole force be transferred

° Only one particle out of each emiſſion from any very ſmall given part of the ſun's ſurface, can ſtrike the earth's ſurface per-

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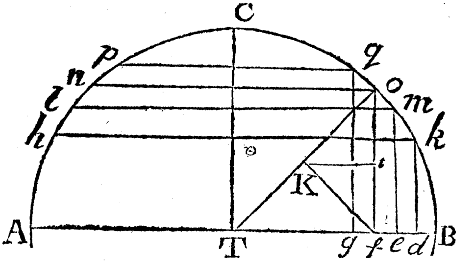
from the iron ball to the globe of the earth, the progressive velocity of the earth's center will be found to be no more, than that with which a body would traverse about $\frac{1}{2}$ of one millionth of one millionth of

pendicularly. The force of every particle, which impinges obliquely, is resolvable into two, one perpendicular to the surface, and the other parallel to it. That part of the force, which is perpendicular to the earth's surface, produces a progressive motion of the whole globe. The other, which is parallel to the surface, contributes nothing to the progressive motion, but tends to produce a rotation of the globe upon an axis. Hence the progressive force of motion, communicated to the globe, is less than it would be, if all the particles struck the surface perpendicularly. It is further lessened upon another account, namely, that the whole of the perpendicular force is not effective in moving the earth's center. I find by computation that the diminution upon the whole is $\frac{1}{2}$. For the ease of the mathematical reader, I shall briefly state the principles upon which this computation of the force with which the earth may be struck by light, has been framed.

The number of particles, which are directed to the earth out of each emission, is to half the number of the whole emission, in the duplicate proportion of the chord of the sun's horizontal parallax, to the chord of 90°: by the known doctrine of Archimedes. Hence, the number of the whole emission being determined, the number of those which tend towards the earth, is given. And the force of each single particle being given, the sum of the forces of that given number is given; and this is the progressive force which would be impressed upon the earth, if all the force of each particle were effective. In what proportion the progressive force is diminished, on account of the various obliquities of impulse, is thus investigated.



Imagine T to be the earth's center and ACB to be half a great circle

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an inch in 100″. This is the utmoſt effect of the force impreſſed upon the earth by each emiſſion. If the emiſſions were inceſſant, this might be conſidered as a central force, counteracting the ſun's attraction:

of the earth, perpendicular to that which ſeparates the enlightened and the dark hemiſphere, and which ſhall be called the terminator. Upon the plane of this ſemicircle, ſuppoſe the terminator, and its parallels in the enlightened hemiſphere, to be projected, into right lines AB, *kh*, *lm*, *no*, &c. which are diameters of the circles reſpectively, of which they are the projections. The ſun's diſtance may be conſidered as infinite; and therefore the rays of light, i. e. the directions of the particles, when they reach the earth's ſurface, are to be conſidered as parallel to each other, and all of them perpendicular to the plane of the terminator. Now imagine the whole enlightened hemiſphere to be divided into innumerable little zones AB *kh*, *hkml*, *mlno*, &c. by ſmall circles parallel to the terminator. Let the breadths of theſe little zones, meaſured upon a great circle paſſing through the poles of the terminator, that is, let the infiniteſimal arcs *Bk*, *km*, *no*, &c. be ſo proportioned to each other, that perpendiculars *kd*, *me*, *of*, &c. being drawn from the extremities of theſe arcs, to the right line AB, which is the common interſection of the great circle ACB, and the plane of the terminator, the infiniteſimal ſegments of that line B*d*, *de*, *ef*, &c. may be equal. Now imagine the particles of light which fall upon any one of theſe little zones, for inſtance, *noqp*, to meet with no reſiſtance from the earth's ſurface, but to penetrate the globe, and to paſs on without refraction or inflection, in the direction perpendicular to the terminator, till they arrive at the plane of the terminator, and there ſuppoſe them to ſtop, and each to lye ſtill, in the place on which it falls. It is evident that the particles of light that fall upon, and have been ſuppoſed to paſs through, the ſpherical zone *pqon*, will, with their proper interſtices, cover that annular ſpace upon the plane of the terminator, which is the orthographical projection of the zone *pqon*, upon that plane, and is compriſed between the circumferences of circles, of which the right lines T*g* and T*f* are the radii. Hence the number of the particles of light, which fall upon the evaneſcent zone *pq on*, are as that evaneſcent annular ſpace

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for its tendency is to puſh the earth directly from the ſun. I need not ſay, that it is infinitely too ſmall, in compariſon of the ſun's attraction, to produce any ſenſible effect.

which they cover, that is, as $gf \times$ the circumference of the circle of which Tf is the radius, that is, as $gf \times$ in the right line Tf. But that part of the force of each particle, impinging on the zone $pqon$, which is perpendicular to the ſurface of the zone, is as of, if TB (the ſemidiameter of the earth) be put for the whole force. For join To, and draw fK perpendicular to To. The particle impinging at o moves in the direction of. Let the right line of then expreſs its whole force, and this force of is compoſed of the two oK, Kf, of which oK is perpendicular to the ſurface of the ſphere at o, and Kf is parallel to it. But $oK : of = of : oT$ or TB. Again, through K, draw Kt perpendicular to of. The force oK is reſolved into two ot, tk, of which ot is perpendicular to the plane of the terminator, and is the only part of the force oK, which tends to produce a progreſſive motion of the globe, in the direction of the impinging particles, that is, directly from the ſun. The other part tK urges the center of the globe along the plane of the terminator; but the forces tK being equal and contrary on oppoſite ſides of, and at equal diſtances from, the perpendicular ray, deſtroy each others effects. Now it has been ſhewn, that the whole force of the particle impinging at o is to that part of its force which is perpendicular to the earth's ſurface at o, as TB to of. And it is manifeſt that oK is to ot, that is, the perpendicular force, of the particle impinging at o, is to that part of it, which is effective in moving the earth's center, as TB to of. Therefore the whole force of the particle impinging at o is to its effective part, as TB^2 to of^2. That is, the effective part is as of^2. The number of particles impinging on the zone, has been ſhewn to be as $gf \times Tf$. The progreſſive force of motion excited in the earth's center, by all the particles impinging on the infiniteſſimal zone $pqon$, muſt be, as the number of the particles and the effective part of each, jointly; that is, as $gf \times Tf \times of^2$, or writing a for TB, and x for Bf, as $\dot{x} \times \overline{a-x} \times \overline{2ax-x^2}$. And this is the fluxion of the progreſſive force of motion excited in the globe, by the particles impinging upon that ſegment of the

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The rotatory forces mentioned in the laſt note if they were infinitely greater than they really are, would not, in the leaſt degree, diſturb the diurnal rotation; becauſe every one of them is deſtroyed, by an equal one, in a contrary direction, on the other ſide of, and at an equal diſtance from, the perpendicular ray.

I have enquired, what may be the utmoſt ſtroke, which the retina of a common eye ſuſtains, when the eye, in a bright day, is turned up directly to the ſun. This force will evidently be at its maximum, if the emiſſion be reckoned at its maximum. The number of particles which enter an eye, looking up directly at the ſun, are to the number out of each emiſſion, which are directed towards the earth, in the duplicate proportion of the diameter of the pupil to the diameter of the earth. And the force with which the eye is ſtruck, is to the ſum of the forces of all the particles which ſtrike the earth, in the ſame proportion. If, therefore, the diameter of the pupil, when the eye is expoſed to the direct impulſe of the ſun's rays, be reckoned $\frac{1}{10}$th of an inch, which I apprehend muſt rather exceed

ſphere, of which $pABq$ is the projection. The number of particles impinging on the zone $pqon$, being as $gf \times Tf$, or as $\dot{x} \times \overline{a - x}$, if each impinged perpendicularly, and its whole force were effective, the ſum of the effective forces impreſſed upon the whole, would be as $gf \times Tf \times TB^2$, or $\dot{x} \times \overline{a^3 - a^2 x}$. And this would be the fluxion of the progreſſive force of motion of the globe excited by the particles impinging upon the ſegment of which $pABq$ is the projection, if all impinged in directions perpendicular to the ſurface, and the whole of their forces were effective. The fluent of $\dot{x} \times \overline{a - x} \times \overline{2ax - x^2}$ is $\frac{1}{4} \times \overline{2ax - x^2}|^2$. And the fluent of $\dot{x} \times \overline{a^3 - a^2 x}$ is $a^3 x - \frac{1}{2} a^2 x^2$.

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than fall ſhort of its real magnitude, in thoſe circumſtances, it will be found that every ſtroke which it receives from them, exceeds not that, which an iron ſhot, $\frac{1}{4}$ of an inch diameter, would give, moving only at the rate of 16,16 inches in a year. This would be the ſtroke if the emiſſion were at its maximum. Is it not owing to the extreme minuteneſs of the fibres of the nerves, that a ſtroke, which is certainly leſs than the $\frac{1}{2084}$th part of this, is not ſuſtained by our organs, without pain?

When $x=a$, the firſt of theſe two fluents is the ſum of the progreſſive forces actually impreſſed upon the whole hemiſphere ACB, and the latter is the ſum of the forces which would be ſo impreſſed, if all the impinging particles impinged perpendicularly, and the whole force of each were effective. But when $x=a$ the firſt fluent becomes $\frac{1}{4}a^4$. And the latter becomes $\frac{1}{2}a^4$. Whence it is manifeſt that the progreſſive motion communicated to the globe of the earth, by the particles of light, is to the force which they would communicate, if the whole force of each were effective, in the proportion before aſſigned, of one to two.

Received